The Need to Reconsider Digital Design Entities

A semantic framework to enhance computable representation of user/space interaction

Armando Trento[1], Antonio Fioravanti[2], Joachim Kieferle[3]
[1,2] Sapienza, University of Rome [2] Hochschule Rheinmain[3]
[1]ing.armando.trento@gmail.com [2]antonio.fioravanti@uniroma1.it [3]joachim.kieferle@hs-rm.de

Reconsidering digital architectural design approaches involves an accurate observation of the relation between human behaviours and spaces. Exploring the reciprocal relationships between people and context, helps better understanding societies' needs and "genius loci" specific identity factors; in other words, the bases of good design. Inclusion of users' behaviours in the design – apart from traditional questionnaires of participatory design – has been enhanced in the last years by the development of behaviour acquisition strategies, influenced by the evolution of sophisticated tools: the last can easily collect/use a considerable amount of data, tracking the actors' use process in different spatial contexts (regional, urban, architectural, interior scale). The present paper, based on our previous research, wants to contribute in sketching a theoretical framework within which it is possible to address a more smart and effective computation of the interaction between users and spaces, and vice versa. The quest is to reflect on a strategy to formalise explicit design knowledge by engineering the required semantic information on top of available simulation systems. An analysis of computable architectural design process implies the investigation of project models anatomy along the CAAD history. By discussing the evolution of those models, knowledge structures and their "design entity" formal representations, this work aims at providing an 'Ariadne's thread' for designers, software developers and academicians in order to enhance consciousness about limits and potentials of the tools they are familiar with.

Keywords: *Design Entities, Behavioural Knowledge, Use Simulation, Polysemantic.*

INTRODUCTION

Reconsidering digital design entities in many fields, representing human behaviour, involves an accurate observation of the human conducts in the built environment and a coherent implementation.

Nowadays it is emerging that these factors in the past decades they were not appropriately considered: the main – quite exclusive - focus of designers has been for a long time, the physical features, approached limiting the research to the Sciences of Architecture and considering only to pass requirements, instead than explore better solutions (Trento and Fioravanti, 2018).

Looking from a historical perspective, starting from the early Sixties only a few pioneers' researchers were involved in exploring cybernetics: their radical approach aimed at the utopia to "create" the *automata*, hardly distinguishable from humans, even anthropomorphic.

In times, the utopian objective was reduced to smaller ones and instead of a unique system, it was fragmented into a plethora of them: like the AI field (and in turn the Expert System), mechanical robots, sensors, language interpretation, semantic interpretations, artificial vision, VR and AR, and so on. To simplify, we can observe that those technologies are brought together and grouped by interfaces to make step-by-step, *ad-hoc* assemblies.

Nowadays, thanks also to the increased computing power, speed nets and constellation of these systems, it is possible to approach the task of modelling the behaviour of users related to the space where they act, having more plausible results.

The theoretical work presented in this paper explores the reciprocal relationship between people and 'context' in a broad sense because it helps in better understanding societies' needs and "genius loci" identity factors; in other words, the bases of good design.

The emphasis is on the importance of a structured representation to handle multiple aspects of the building process, including brief to design, construct, maintain, refurbish and demolish as well as actors, clients, citizens, firms, and also behaviours, psychology, etc.

We assume that all those entities should be digitally well-formalized to be computable at the abstraction layer they need.

THE QUEST FOR PEOPLE'S INCLUSION

At present, the task of predicting and assessing if and how an existing spatial context will effectively host new uses and/or users is still unsupported and completely left to designers' – implicit – expertise and imagination.

To enhance the process, the control and, in the end, the final quality of the product and use it is time to reconsider the digital design, space users' well-being and productivity according to a deeper understanding and vision of what has happened.

The inclusion of people in the design process has always been considered, but their behaviours were modelled as an average of their actual space uses as well as the intimate emotion related to space and ornament. Only in recent years, the design process/product in this regard has been enhanced by the development of acquisition strategies, influenced by the evolution of sophisticated tools.

The last ones can easily collect/use a considerable amount of data, tracking the actors' use process of a space (regional, urban, architectural and interior scale) (Trento and Fioravanti 2016).

Uses and informing spaces

The investigation problem of this work is how available information about users' habitual behaviours can inform new projects and support the delivery of value and understanding in spaces.

The architectural space does not only cause behaviours but is also influenced by Actor's behaviours (Gibson 1979).

In a use-oriented design approach, Actors' behaviours can be influenced by Context capabilities and vice-versa: space can be influenced by actors' capabilities.

Context, intended as a general extension of the physical environment concept, including non-physical aspects, is where the Actor space use process takes place (Turner 2005).

The present paper wants to contribute to sketching a theoretical framework within which it is possible to address a more efficient and effective computation of the interaction between users and spaces (and vice versa).

In order to understand the need for new developments, we present an analytical discussion regarding the evolution in CAAD history of "design entity" formal representations.

DESIGN USING SIMULATIONS

The problem addressed by the authors' research group since the last decades is the conceptual development and validation of a modelling and simulation platform to test different use scenarios in order to understand and evaluate the relationship between humans' users and the designed space, namely if and how the re-designed environment will be able to host its intended new functions for the users and their specific use processes.

The research framework, as outlined in previous authors' papers (Trento and Fioravanti 2016), starts from occupancy analysis (users's profiling, context and reciprocal interaction) in order to collect and formalize Behavioural Knowledge.

The general goal is to support design and evaluation, by means of both static simulation (Data-driven and Ontology-based) of a specific artefact, and dynamic simulation of a contextualized use process (Agents+AI).

Behavioural Knowledge and Cognition

According to Vernon (2006) generally, we can classify two different approaches for computing Cognition, having a diverse position on knowledge:

- On the one side the *Cognitivist* method aims at representing symbolic information processing. It takes a mostly static interpretation of knowledge, represented by symbol systems that refer, bidirectionally, to the physical reality that is external to the cognitive agent. This knowledge raises processes of reasoning on the representations provided by the perceptual apparatus. As a consequence, it plans actions in order to achieve programmed goals. The *Cognitivist* approach to knowledge representation can be best characterized by the traditional perception reasoning-action cycle.
- On the other side the *Emergent Systems* approach (including Connectivism, Dynamic systems, and Enactive systems) takes a mainly dynamic or procedural view of knowledge and sees it more as a collection of skills that understand the "how to do" things.
  The "cognitive agent" is on a higher level, thus it depends on the agent, as well as on the environmental context. Its behaviour covers both a short time-scale as well as a longer time-scale. Whereas a short time-scale can be described as reflexive and adaptive, a longer time-scale is characterized as deliberative and cognitive. Their behaviours can be best characterized by perceptual-motor skills.
  Both, the agent and its environment are developed in real-time, which is substantial for cognition and its emergence or appearance.

So there is another crucial difference between the two paradigms:

- In the *Cognitivist* paradigm, it is mostly based on the designers' frame-of-reference. External designers, or knowledge engineers' observations, descriptions, and models are the basis for the configuration of perceptual capacities.
- In the *Emergent Systems* paradigm, it is mostly based on the agents' frame-of-reference. The perceptual space is defined by the action space. The capacities are based on an historic enactive embodied development, that grounds on the comprehensive knowledge of the cognitive agent within its world. In the enactive emergent paradigm, true cognition has to be developed in an agent-centred manner, meaning to interact, learn, and co-develop with the environment.

Semantics for enhancing simulation

Compared to the present-day state of the art in CAAD, mainly populated by plenty of Agent-Based Systems, our research approach focuses on assigning meanings – on the fly – to structured behaviours in a structured context.

The quest is to reflect on possible paths to better formalize explicit design knowledge by engineering the required semantic information on top of available simulation systems (Gero 2017).

This vision is strictly related to the higher and new abstraction layer that we place on other existing abstraction layers designers currently use. This new layer should be formalised and computable to make individuals fully aware of their partial knowledge and understanding, both related to problems they have. As this layer is incrementally populated, it can provide additional knowledge to designers.

Focusing on AEC sector, we assume that semantics originates from the topic of the systemic decomposition/classification of the *Building Organism*.

According to this vision, the building is a complex organism defined by means of a series of Realms: Process, Product, Context and Users. As this series is incremental and flexible, when it is needed, it is possible to add new realms or switch off part of realm during the project evolution.

In order to contribute to a reconsideration of digital design in AEC field, the modelling task must rely on a suitable formal structure for representing both, on one side the *design entities* belonging to the Building Process, Product, Context and Users realms, and on the other side the connections between those entities (Fioravanti et al., 2011).

If we assume the analogy between language and design, as it is generally known that many words convey several concepts and thus possess the corresponding number of meanings, also the design entities (Building Process, Product, Context and Users) usually assume different meanings and behaviours.

The complex relations between meanings and words were first noted by the Stoics. "However, 'concrete research into the multiplicity of meaning only began in the 18th century' and was continued in the 19th century by linguists interested in meaning from the point of view of etymology, historical lexicography or historical semantics" (Nerlich 1992). The 19th century linguist Bréal, whose research into polysemy marked a new starting point, shifted the study of polysemy away from lexicography and etymology and investigated polysemy as "synchronic pattern of meanings surrounding a word, which is itself the ever-changing result of semantic change" (Cuyckens, Zawada 2001).

REPRESENTATION OF DESIGN ENTITIES

In order to address more consciously, the definition of a suitable structure for formalizing project-process semantics, we have been tracking the evolution among the CAAD approaches in modelling *design entities*.

Follows a review and a comparison of the progress achieved by the academia and industry in the digital representations of *design entities*.

Entities discussed, both tangible and intangible, are those regarding architectural spaces, building components and design process- procedures for a project as more extensively listed in the introduction.

A historical overview

The different paradigms to define building entities regarding many aspects of the entire Building process represented in Computer science have been proposed starting from the second half of the last century, and demonstrated their potentials and limits by means of applications.

It is crucial to understand, how the underlying layer representation in computer science can impact the upper representation layers and the application programs, and thus affects the non-fluent design process as well as the designers works.

The final goal is to have a real and high human no-human interaction thanks to a computer-powered collaboration. This implies a deeper design understanding of architecture, Masters made in marvel works and details.

A key point noted is how they had the capacity to make holistic buildings and components mainly where an entity satisfied many – sometimes contrasting – objectives.

Making a synthetic swept of main paradigms it is possible to devise [or work out] three steps:

- In the nineteen sixties, boosted by large prefabrication industries, the first building entity classification paradigm has been promoted as a set of parts, and the "building system" concept introduced. Many standards all over the world adopted similar classifications. Theorical foundation in this field can be found in Christopher Alexander's pioneering work. It was an excellent systematisation of previous ideas, which could have had origin in the open prefabrication at Bauhaus in the Thirties, but the actual results were not so good ( ) in Italy the early settler were P.N. Maggi together with G. Ciribini.

The main idea of this classification was a hierarchical one, and even if in general it was powerful, the practical applications were difficult to be applied because it was rigid, not very clear to many designers or, better they were not accustomed, nor well educated for industrialised design and construction.

Later on this way of thinking, in the nineteen seventies many theorists understood the building as a hierarchical set. Subsequently, with the spread of OOD and OOP, the entity representation became more common according to different context, but the combinatorial explosion to define sub-types remained. As a matter of fact, the same building component or, in general, an entity must have two different labels if used for different purposes, so actually becomes two different entities. That is a strong limitation not only for trivial things as can be a component, a joint, a procedure, but also for higher reasoning layers where syntheses are important.

Many building codes delt with this approach of entities like spaces/ components representation (e.g. STEP draft 10303) then, partially, they merged into the IFC families (Björk et al. 1997). This approach survives till recent times (Eastman 1999) and it is still predominant in present days on BIM programs.

- In the nineteen nineties, pioneer research adopted a new approach where the entities could have multiple one-at-a-time 'parents' (Authors YYY1), integrating the hierarchy structure with an explicit topology (Beetz 2006). Moreover, thanks to the ontology representation, an entity can have different meanings according to its own different actor. This paves the way to a more flexible building entity that could be checked by requirements belonging to different contexts and/or actors.

  An important goal was to implement an effective collaboration in design (Kvan 2000; Achten 2009), and make the Collaborative design effective thanks to the explicit constraints/explanations made by different actors, etc.
- At the dawn of the new millennium advanced research proposed the '**polysemantic**' design entity that could have multiple 'parents' at the same time (Bourreau 2020).

  That is, it could take on **different meanings depending on the context and domain of the actor using it** (please refer to "Figure 1"), or it could have multifunctional uses (Fioravanti et al., 2011; Werbrouck 2022).

  New knowledge-based systems synergically work with the basic commercial models (IFC-based) by means of ontologies and graphic systems (Pauwels 2022), to enable semantic reasoning.

  It is important to underline that these different paradigms are not strictly related to a specific programming language, as each one can be implemented with many of those languages.

A FRAMEWORK TO FORMALIZE SPACES AND HUMAN BEHAVIOUR

As previously mentioned, the core of the modelling task is to ensure an efficient connection between building process, product, context and users, in order to support design and evaluation and simulation.

To model and test knowledge related to the user behaviour in a building environment we need:

1. Spaces that are characterized by physical parameters related to environmental comfort but also with space-time Functional aspects, Potentialities or Behaviours, Capability or Action (Wurzer 2010);

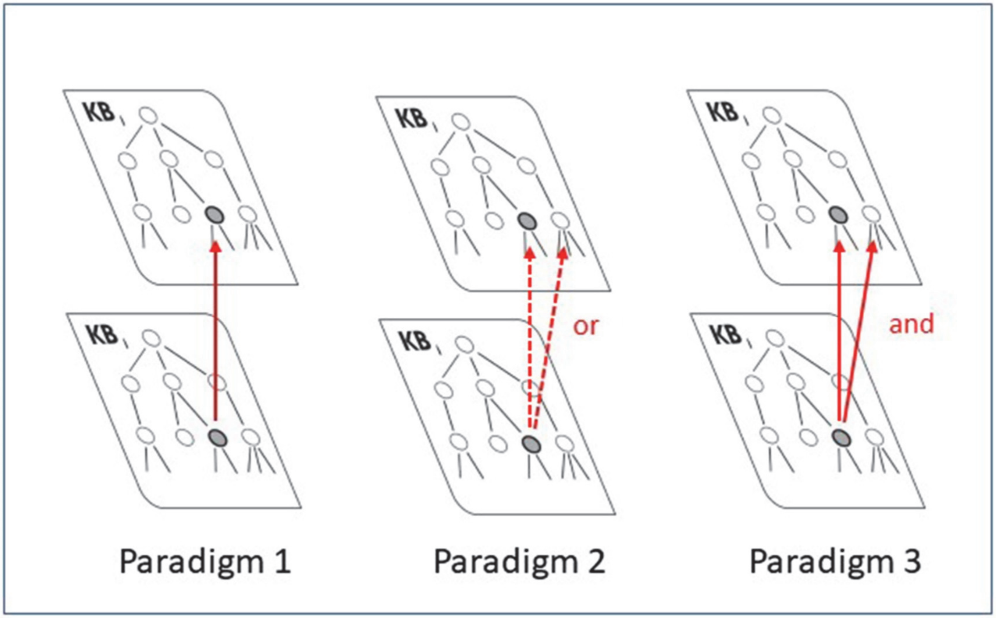

Figure 1
"Polysemantic" *design entity*: having multiple parents, can support context dependent semantic reasoning

2. A Use Process Knowledge structure (Author 2013) that includes Skeleton Activities and Intermediate Activities (Tabak 2004);
3. An Agent-based simulation, enhanced by associating agents with AI resources (upper ontology level), that reside not only in the Actors' Knowledge-based systems, but also in other systems (Context, Product, Process).

Implementation strategy

The implementation strategy, as discussed in a previous work (Fioravanti and Trento 2018) outlines a multilayer organization:

- 1st layer. Object based for project data logical automation;
- 2nd layer. IFC/Ontology-based for semantic reasoning;
- 3rd layer. Agent Semantics/Cognitive based to compare goals and explore consequences and side effects of design choices.

CONCLUSIONS

At present, the task of predicting and assessing if and how an existing environment will effectively host new uses and/or users is still unsupported and completely left to designers' expertise, implicit knowledge, and imagination.

In order to address more consciously, the definition of a suitable structure for formalizing project-process semantics, we have been tracking the evolution of the CAAD approaches in modelling *design entities*.

By analysing the anatomy of computable project models along the history this paper aims at providing a compass for designers, software developers and academicians in order to enhance consciousness about limits and potentials of the tools they are familiar with.

It has been observed that in more recent years the *design entity* formal representation, by means of computable ontologies, allows for polysemantic (multiple 'parents' at the same time).

Different meanings assigned to building entities depending on the context and domain of the actor using it, open to a more sophisticated and effective semantic reasoning.

ACKNOWLEDGEMENTS

The research has been partially funded by FFABR 2017 – *Finanziamento Fondo per le Attività Base di Ricerca*" (Grant for Financing Research Basic Activities), and by the National Interest Research Program 2017 (PRIN – *Progetti di Ricerca di Rilevante Interesse Nazionale* – Prot. 2017EY3ESB) of MUR (Italian Ministry of University and Research) titled: "A Distributed Digital Collaboration Framework for Small and Medium-Sized Engineering and Construction Enterprises".

REFERENCES

Gibson, JJ 1979, The Ecological Approach to Visual Perception, Houghton Mifflin Harcourt (HMH), Boston.

Turner, P 2005, 'Affordance as context', Interacting with Computers, Science Direct, Elsevier, 17, pp. 787-800.

Glanville, R. (2015). A (cybernetic) musing: Wholes and parts, chapter 1. Cybernetics & Human Knowing, 22(1), 81-92.

Vernon, D 2016, 'The space of cognitive vision', in Christensen, HI and Nagel, HH (eds) 2016, Cognitive vision systems: sampling the spectrum of approaches, Springer, Heidelberg, p. 7–24.

Elçi, A. Koné, M.T. and Orgun, A. (2011) "Semantic Agent Systems: Foundations and Applications" Springer-Verlag Berlin Heidelberg.

Gero, JS 2017 'Cognitive Design Computing', Proceedings of eCAADe 2017, Rome, pp. 37-40.

Trento, A and Fioravanti, A 2018, 'Contextual Capabilities Meet Human Behaviour - Round the peg and square the hole', 36th Proceedings of eCAADe 2018, Lodz, Vol. 1, pp. 613-620.

Björk BC, Löwnertz K, Kiviniemi A 1997 'Iso Dis 13567 - The Proposed International Standard for Structuring Layers in Computer Aided Building Design', ITcon Vol. 2, pp. 1-23. https://www.itcon.org/1997/2.

Nerlich, N 1992 Semantic Theories in Europe 1830-1930. From Etymology to Contextuality. Amsterdam, Philadelphia: John Benjamin's.

Cuyckens, H, Zawada, B 2001 Polysemy in Cognitive Linguistics. Selected Papers from the Fifth International Cognitive Linguistics Conference, 1997. Amsterdam, Philadelphia: John Benjamin's.

Eastman, C.M. 1999 Building Product Models - Computer Environments, Supporting Design and Construction, 1st Edition, CRC Press, Boca Raton.

Trento, A and Fioravanti, A 2016 'Human Behaviour Simulation to Enhance Workspace Wellbeing and Productivity – A BIM and Ontologies implementation path', 34th Proceedings of eCAADe 2016, Oulu, Vol. 2, pp. 315-325.',

Beetz J, van Leeuwen JP, de Vries B 2006 'Towards a topological reasoning service for IFC based building information models in a semantic web context', Joint International Conference on Computing and Decision Making in Civil and Building Engineering, June 14-16, 2006 - Montréal, Canada.

Kvan T 2000 'Collaborative design, what is it?', Automation in Construction (9) 409-415.

Achten H and Beetz, J 2009. 'What happened to collaborative design?'. In G. Cagdas & C. Gulen (Eds.), Computation: The new realm of architectural design - Proceedings of the 27th Conference on Education and Research in Computer Aided Architectural Design in Europe, pp. 357-365. Istanbul.

Bourreau P, Charbel N, Werbrouck J, Senthilvel M, Pauwels P and Beetz J 2020 'Multiple

inheritance for a modular BIM', in https://bim4ren.eu/.
Fioravanti A, Loffreda G and Trento A 2011 'An innovative comprehensive knowledge model of architectural design process', International Journal of Design Sciences and Technology, Vol. 18(1) 1-18.
Werbrouck J, Pauwels P, Beetz J and Mannens E 2022 Mapping Federated AEC projects to Industry Standards using dynamic Views, LDAC 2022 - 10th Linked Data in Architecture and Construction Workshop, May 29, 2022, Hersonissos, Greece conference.
Fioravanti A and Trento A 2018 'Close Future: Co-Design Assistant – How Proactive design paradigm can help', 37th Proceedings of eCAADe 2019, Porto, Vol. 1, pp. 155-160.
Pauwels P, Costin A and Holten Rasmussen M 2022 'Knowledge Graphs and Linked Data for the Built Environment', in Industry 4.0 for the Built Environment: Methodologies, Technologies and Skills, Marzia Bolpagni, Rui Gavina and Diogo Ribeiro (Eds), Structural Integrity Series, Vol. 20, pp. 157-183, Springer.
Wurzer, G., Fioravanti, A., Loffreda, G., & Trento, A. (2010). Function & Action: Verifying a functional program in a game-oriented environment. In FUTURE CITIES (28th eCAADe Conference Proceedings) (pp. 659–664). http://hdl.handle.net/20.500.12708/63773